ASSESSMENT OF BALANCE BEHAVIOUR, EYE-MOVEMENT, AND ATTENTION: A STEP TOWARDS A MORE COMPREHENSIVE CONCUSSION RETURN-TO-PLAY PROTOCOL

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Abstract

Concerns associated with head injuries have come to the forefront as head trauma events in the National Hockey League (NHL) and National Football League (NFL) bring to light the prevalence and effects of concussions. Accordingly, proper assessment and management of head injuries are growing areas of interest among the general public and researchers. At this point, most sports leagues and teams have established the need for concussion protocols and have set standards that must be met when an injury occurs or is suspected. In an effort to make assessments accessible to the general public, many tests are simplified to computer tests that require very little training or cost to administer. However, these assessment protocols are often not thorough enough to detect the various potential deficits and symptoms that can occur after a head injury. Of the various possible symptoms of a concussion, the highest testable deficits are balance dysfunction and dizziness. Further, most tests used to evaluate athletes comprehensively, are not ecologically relevant. The increased challenges athletes incur through their participation in sport in their everyday lives must be considered when developing baseline testing. The present research study aimed to aid in the correction of the previously mentioned inadequacies. A test-retest design used 4 instruments to evaluate 20 healthy individuals ranging in age from 17-25. The BESS, ANT, Wii Fit Balance Board, and Mobile Eye XG glasses were used to measure static and dynamic balance, attention, and gaze. The results indicate that the selected measures were stable and consistent with traditionally used protocols for healthy individuals. By analyzing the

test-retest reliability of the Soccer Heading Game on the Wii Fit Balance Board while wearing an eye-tracking device, a more ecologically relevant and comprehensive test is available to assess an athlete's balance.

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List of Abbreviations

ABI- Acquired Brain Injury

ANT- Attention Network Test

ASL- Applied Science Laboratories

BESS- Balance Error Scoring System

CoM- Center of Mass

CTE- Chronic Traumatic Encephalopathy

DVAT- Dynamic Visual Acuity Test

GST- Gaze Stabilization Test

ICC- Intraclass Correlation Coefficient

ImPACT- Immediate Post-Concussion Assessment and Cognitive Testing

mANT- Modified Attention Network Test

mTBI- Mild Traumatic Brain Injury

NCAA- National Collegiate Athletic Association

PCSS- Post-Concussion Symptom Scale

RTP- Return to Play

SAS-Statistical Analysis System

SCAT- Sport Concussion Assessment Tool

VOMS- Vestibular/Ocular Motor Screening

VOR- Vestibulo-Ocular Reflex

WBB- Wii Fit Balance Board

Chapter 1

Introduction

1.1 Background

Concussion is defined as a complex pathophysiologic process affecting the brain induced by traumatic biomechanical forces (Aubry et al., 2002, p. 6). Concussion or mild traumatic brain injury (mTBI) is one of the most common neurological disorders, accounting for approximately 90% of all brain injuries reported in emergency departments (Saulle & Greenwald, 2012). Previous research on rates of concussion-related trauma indicates that an estimated 1.6-3.8 million concussions occur in the United States per year, and of those documented cases, some 300,000 are related to participation in sport and organized physical activities (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). However, these numbers may be an under representation of the true number of concussion events, as many athletes neither seek medical attention for suspected concussion injuries, nor are they likely to report their symptoms (Saulle & Greenwald, 2012). In fact, under-reporting of concussion injuries has also been reported for the general population. According to DeKosky, Ikonomovic and Gandy (2010) more than 1.5 million Americans will report a concussion with no loss of consciousness and no need for hospitalization. Similarly, DeKosky et al. (2010) suggest that an equal number of individuals will report a concussion with conscious impairing trauma but insufficiently severe to require long-term hospitalization.

Concussions are often considered by clinicians to be among the most complex injuries in sports medicine to diagnose, assess and manage (McCrory et al., 2013). One factor leading to the complexity is the variety and severity of possible symptom categories which may include, but are not limited to, somatic, emotional, physical, behavioural, and cognitive outcomes.

Concussion-related symptoms may include confusion, loss of memory, loss of consciousness, loss of spatial and temporal awareness, headaches, migraines, speech impairment, dizziness, nausea, balance disturbances, oculomotor control reduction, vision impairment, speech reduction, gait unsteadiness, and poor coordination (Aubry et al., 2002). Due to the variability of the symptoms and the multiple mechanisms of the injury that can contribute to sport-related concussions, concussion injuries are rarely similar, making accurate assessment and management arduous (Aubry et al., 2002).

Another layer of complication can be added to concussions if someone suffers repeated head injuries. Incidents of repeated trauma to the head are problematic as they have been linked to health problems later in life (Saulle & Greenwald, 2012). One risk is chronic traumatic encephalopathy (CTE), which is a neurodegenerative disease that is a long-term consequence of single or repetitive closed head injuries for which there is no treatment and no definitive premortem diagnosis (Saulle & Greenwald 2012). CTE has been closely tied to athletes who participate in contact sports like boxing, American football, soccer, professional wrestling, and ice hockey (Saulle & Greenwald, 2012).

CTE is relevant because it has been shown that over 16% of the high school and collegiate level athletes that suffer a concussion experience a second concussion in the same season (Gessel, Fields, Collins, Dick, & Comstock 2007). This outcome further highlights the need for valid and reliable diagnoses, treatment, and testing for concussions, to ensure that athletes do not put themselves at risk by returning to play before they are fully recovered. At this point, no single tool can fully quantify a concussion injury (McCrory et al., 2013), making proper diagnoses almost impossible. One reason for this is that many tests currently being used are not specific and specialized enough to be ecologically relevant to athletes. For a test to be ecologically relevant for athletes, it would have to include the added day-to-day challenges that occur during practices and games.

1.2 Rationale

Balance assessment is extremely important in the recovery process after a sports-related concussion. Because there are a large number of possible symptoms (related to concussion), it is important to focus on the most common, and it is reported that in over 75% of all sports-related concussions, reduced balance and dizziness are symptoms (Guskiewicz, Ross, & Marshall, 2001; Marar, McIlvain, Fields, & Comstock, 2012; Riemann & Guskiewicz, 2000). These symptoms include balance disturbance, which is the inability to stand in an upright posture without deviating outside the limits of the base of support (Guskiewicz, 2011). A balance disturbance could place an athlete at an increased risk for additional injury through the mechanisms of falling and/or collisions with another player or the playing environment (Murray, Salvatore, Powell, & Reed-Jones 2014). This risk highlights the need to have a test that is both reliable and valid to assess balance measures.

Currently, the most commonly used balance assessment is the balance error scoring system (BESS). The BESS was developed by Guskiewicz and coworkers at the University of North Carolina - Chapel Hill, as a low technology, low cost, effective sport-related concussion assessment for balance (Guskiewicz et al., 2007). The BESS involves three static stances (i.e., double leg, single leg, and tandem) on two different surfaces (floor and foam pad) with the participants eyes closed to assess postural stability. However, it has been found to only be sensitive enough to measure balance dysfunction up to the third day of recovery (Peterson, Ferrara, Mrazik, Piland, & Elliott, 2003). The BESS is limited in that it is a static test, and is scored based on the rater's interpretation of an error (moving from the specific stance), which can result in low inter-rater reliability (Finnoff, Peterson, Hollman, & Smith, 2009).

Traditionally, tests of balance like the BESS in the clinical setting minimize visual inputs to assess the control of balance, dependant on the visual and somatosensory functions (Finnoff et al., 2009). However, this approach could be a mistake, because the visual and vestibular systems that control balance are directly linked (Shumway-Cook & Woollacott 2007). The vestibular system provides information on the position of the head in space and sudden changes in the direction of movement of the head, and these vestibular inputs help stabilize the eyes and body to maintain postural stability and balance (Shumway-Cook & Woollacott 2007). These concepts would help explain why issues with the vestibular system following a concussion injury are considered to be the most likely reason for the inability to maintain balance (Shumway-Cook & Woollacott 2007). However, when an individual is tested with eyes closed, the visual system and associated reflex mechanisms do not contribute directly to the assessment, making it possible that tests without visual inputs are insufficient to fully measure balance.

It is the vestibulo-ocular reflex (VOR) that enables the eyes to maintain a steady focused image in relation to head movement, referred to as gaze, and is registered by the vestibular system (Shumway-Cook & Horak 1986; Shumway-Cook & Woollacott, 2007). By adding a test that incorporates a visual task while the individual is simultaneously moving and executing a decision, not only can the VOR and related fixation reflex be monitored, but it becomes ecologically relevant for athletes because traditional balance tests are static tests that have the athlete's close their eyes for the entirety of the test.

Historically, in clinical evaluations following a suspected concussion injury, most tests isolate a specific symptom that an individual reports and assess the individual one symptom at a time. For example, the previously described BESS is a test of static balance, and the Attention Network Test (ANT) is used to evaluate a person's attention. The ANT was developed to measure and quantify the processing efficiency of the three attention networks (alerting, orienting, and executing functions) (Fan, McCandliss, Sommer, Raz, & Posner, 2002). However, with head injuries the number, severity, and variety of symptoms can be different in all cases, so a test that offers the potential to measure multiple concussion related symptoms needs to be identified and analyzed.

The Wii Fit balance board Soccer Heading Game presents this possible capability. Not only as a measure of balance, but also to evaluate an individual's attentional functioning. Also, the Wii Fit Soccer Heading Game (i.e., a dynamic balance task played on the Wii Fit balance board) demands dynamic movements, and the game console generates the score automatically, which removes problems of inter-rater reliability that occur in the BESS. The added visual measures of gaze deviation and centre of gaze, as part of the Wii Fit Soccer Heading Game, makes it more ecologically relevant than the BESS because the test simulates visual, motor and mental challenges that are more likely to occur in a sport environment. Consistent goal-directed behaviours like the Wii Fit Soccer Heading game are dependent on the ability to sustain attention over time. A predominantly right-sided fronto-parietal system is often engaged during attentionally demanding tasks (Coull, Frackowiak, & Frith, 1998; Paus et al., 1997), and damage to these regions can lead to impairments of sustained attention (Malhotra, Coulthard, & Husain, 2009; Rueckert & Grafman, 1996). The Wii Fit Soccer Heading Game requires attention to be sustained throughout the task, as the subjects are not only shifting their centre of mass and controlling balance while doing so, but also are being presented with distractor items that they must attempt to avoid. This task is made more difficult with one of the distractor items being a panda head that has the same colouring and similar shape as the soccer balls, and with the presence of distractors that are in no predictable pattern or sequence. This is a novel characteristic in concussion based testing as many tests are repetitive and more predictable, which adds to practice effect and learnability, making testing less accurate.

1.3 Purpose

Primary Purpose:

The purpose of the study was to assess the test-retest reliability of the BESS, the Wii Fit Soccer Heading Game, a measure of gaze deviation and a measure of centre of gaze, and three measures of attention (i.e., alerting, orienting, and executive control-decision making) based on the Attention Network Test. It is proposed that the Wii Fit Soccer Heading Game, which can be described as a low-cost, user friendly, portable measure of both balance and attention, will demonstrate the characteristics of ecological relevance. Ecologically-relevant testing is the term used in this study to refer to the ability of a test to replicate the tasks, activities, and challenges that occur in a person's average daily life (Jovanovski, Zakzanis, Campbell, Erb, & Nussbaum, 2012).

Use of the Wii Fit device requires greater dynamic postural control and higher order cortical sensory integration than the currently adopted BESS, which is a static balance test. Including a measure of distractor scores will enable the use of an implicit measure of both balance and attention. An objective of this research is to determine if the Wii Fit Soccer Heading Game can be used as a tool to assess balance, and attention in athletes who have reported a concussion, and thereby provide essential evidence for return to play decisions.

Measures of the Wii Fit Soccer Heading Game were also tested for construct validity, which determines the degree to which certain explanatory concepts or constructs account for performance on the test, and is evaluated by investigating what qualities a test measures (Messick, 1993). In simple terms this gives the ability to assess whether measures of the Wii Fit Soccer Heading Game were measuring what was hypothesized. Soccer Heading Game overall and distractor scores were compared to ANT scores for convergent validity. Discriminant validity was determined by comparing BESS scores to Soccer Heading game overall and distractor scores. The purpose of this test of validity was to determine whether or not the Wii Fit is testing something outside of the balance aspect of the BESS. If the Wii Fit Soccer Heading game demonstrated construct validity then it would suggest it had the ability to test for something that the BESS alone was not able to.

<u>Secondary Purpose:</u>

The secondary purpose of this study was to show the relationship between body and eye stabilization. The potential relationship was evaluated by comparing the overall Wii

Fit Soccer Heading Game score to the centre of gaze and eye deviation scores measured with the Mobile-Eye Tracker(™) worn while completing tasks on the Wii Fit Soccer Heading Game. An individual was expected to demonstrate body and eye stabilization when higher game scores correlate with both lower eye deviation scores and higher center of gaze percentages.

1.4 Research Hypothesis

It was expected that the Wii Fit Soccer Heading Game would demonstrate reliability estimates that were consistent with scores on the BESS. Similarly, it was expected that elements of the Wii Fit Soccer Heading Game which are based on attention functions would also be correlated to scores on tests of attention. Measures of the Wii Fit Soccer Heading Game were expected to show construct validity. It was anticipated that higher Wii Fit Soccer Heading Game scores would correlate with lower eye deviation scores and higher center of gaze percentages.

Chapter 2

Review of Literature

2.1 Baseline Testing

A baseline test in concussion assessment is considered a test that is done pre-injury. This means that in most cases baseline testing occurs during (or preferably before) pre-season training. Baseline tests are used to establish a pre-injury reference to which an individual will be compared following an injury. It is expected that by identifying a stable measure of selected physiological functioning at baseline, there will be a clear indication of impairment caused by the concussion injury (Randolph, 2011). Baseline assessments are expected to provide more accuracy in evaluating the magnitude of an injury when compared to self-reported symptoms.

The use of baseline testing is widespread and currently mandated in football and hockey programs (among other sports) at the elementary, high-school, college and university levels throughout the United States and Canada, as well as in professional sports such as the National Football League (NFL) and National Hockey League (NHL) (Randolph, 2011). The directive to use baseline testing occurred at least in part after The National Athletic Trainers' Association and the International Consensus Statement on Concussion in Sport recommendations to use an individual-centered standard that compares a person's post-injury score to the baseline (pre-injury) scores (Dungan, 1996; Guskiewicz et al., 2004; McCrea et al., 1998; McCrory et al., 2009). The difference between the two scores is used to identify deficits and dysfunction resulting from a concussion (Guskiewicz et al., 2004; McCrory et al., 2009). Standardized baseline testing throughout teams and leagues allow for a certain amount of uniformity that is needed in the diverse and sometimes inconsistent area of concussion assessment and testing.

However, the practice of baseline testing does have its critics. Randolph (2011) does not support that idea that the benefits of testing have been proven at a high enough rate to warrant the increased use of baseline testing that has occurred. His work dismissing and diminishing the use of baseline tests states that the serious risks associated with sport-related concussion were unlikely to be modified by baseline testing. This was based on his findings that the vast majority of deaths and long-lasting neurological impairments are secondary to acute subdural hematomas, which cannot be prevented by baseline testing. Randolph also pointed out that “the only study exploring possible risks leading to repeat concussions that have been published to date concluded that the risk was not diminished by ensuring that players were symptom-free before return-to-play. It is unclear; therefore, what risks possibly could be modified by the routine use of baseline testing, despite the ubiquity of this practice” (p. 23).

In response to Randolph’s criticisms it should be pointed out that the battery of baseline tests that he was assessing and basing his conclusions on were from a review done in 2005 that he himself had written. After 2005 more sensitive and specific tests have been developed that have the potential for more comprehensive and effective assessment at baseline.

2.2 Ecologically-Relevant Testing

One of the problems in gaining a better understanding of the symptoms of head injuries is the discrepancy between the tasks that are presented in clinical tests and the challenges that occur naturally from aspects of daily living. This may be in part due to the limited ecological relevance of traditional measures of executive functioning post-concussion (Jovanovski et al., 2012). More ecologically relevant tests can introduce the potential for higher associations between performance on tests and everyday challenges that are present in a person's life. This higher association could lead to better understanding of a patient's symptoms, and therefore, of the range, severity, and variety of concussion symptoms, in general.

The most widely-used baseline test used in concussion assessment is ImPACT (Lovell, 2005). ImPACT is an example of a non-ecologically relevant test for athletes looking to return-to-play. The test measures a player's symptoms, verbal and visual memory, processing speed, and reaction time, and is administered online for individuals or groups (Lovell, 2005). Because ImPACT is performed on a computer workstation it does not have the ability to challenge the athlete in their playing environment. This highly-used test lacks ecological relevance for athletes because of the environment it takes place in, and the lack of movement involved. Accurate evaluations should emulate game-like parameters and use environmentally relevant dynamic assessments. An example of this would be having soccer players perform their fitness test on a turf soccer field, while hockey players perform it on ice. It would lack ecological relevance if both did it on a basketball court. They should also replicate an athletic sporting match by introducing an unexpected and ever-changing environment.

2.3 Balance Error Scoring System (BESS)

The Balance Error Scoring System (BESS) is a clinical test battery that uses modified Romberg stances on different surfaces to assess postural stability (Valovich, Perrin, & Gansneder 2003). Because clinicians often do not have access to an instrumented balance testing device like a force plate (which is the gold standard for accurately measuring balance based on center of pressure computations obtained from measures of ground reaction forces and moments), the BESS is suggested to be an inexpensive, portable, and practical tool used for both sideline and clinical assessment. The test is easy to administer as the only equipment necessary is a stopwatch and a standard sized foam pad (Guskiewicz, 2011).

The BESS is the most widely used post-concussion balance test (Guskiewicz, 2011), yet there are some limitations. Because scoring on the BESS is subjective, one issue is low intra-rater and inter-rater reliability values (Finnoff et al., 2009). An increase in this value would be necessary before changes in postural stability could be attributed to the participant in the test rather than the individual that is scoring the test (Finnoff et al., 2009). A practice effect was also found in high school athletes with repeated administration by Valovich et al. (2003), however, Reimann et al. (1999) did not find a practice effect with collegiate athletes over three test sessions. The BESS was reported to have low sensitivity values (Guskiewicz, 2011), and the inability to detect balance dysfunction after seven days post-injury, while some believe that it is only useful up to three days post-injury (Murray, Salvatore, Powell, & Reed-Jones 2014).

2.4 Wii Fit as a Measure of Balance

It is believed that dynamic standing balance measurement tools appropriate for use in the clinical setting need to be developed and assessed for reliability and validity, as dynamic proprioceptive balance training may be the key intervention to improve postural control in athletic situations and preventing some injuries in sport (Emery, 2003). Many of the clinical tools for balance measurement are inappropriate for use in a healthy active population, as they fail to provide sufficient challenge to balance or they are restricted to static balance measures and do not evaluate dynamic balance (Emery, 2003). Likewise, most laboratory measures for balance are costly, highly technical, and often non-portable (Emery, 2003).

The Nintendo Wii Fit™ was released as a means of improving basic fitness and overall well-being in December of 2007. "Despite this broad mission, the Wii Fit has generated specific interest in the domain of neurorehabilitation as a bio-behavioural measurement and training device for balance ability" (Goble, Cone & Fling, 2014, p.1). Some of the populations using the Wii Fit as a training tool and assessment for balance include (but are not limited to) older adults, those with Parkinson's disease, cerebral palsy, multiple sclerosis, chronic stroke, and concussion (Goble, Cone & Fling, 2014). As a result of the studies done with concussed individuals, the NCAA has made recommendations that the Wii Fit be used as an alternative method to assess postural control after a concussion episode and during the return-to-play (RTP) process (National Collegiate Athletic Association, 2009-2010).

The Wii Fit Balance Board may be more accessible than more sophisticated tools like a force plate and some research has been done to see how data produced by the two compare. For example, Clark et al. (2010) examined the Wii Fit Balance Board's (WBB) reliability and validity versus a laboratory-grade force plate based of centre of pressure (COP) path length. The results showed that both the WBB and the force plate demonstrated good to excellent COP path length test-retest reliability within- and between-devices on all protocols. The results also showed that the WBB was valid in comparison to the laboratory-grade force plate and suggested it was a suitable balance assessment tool for a clinical setting.

These findings, however, have been subject to criticism. For example, Reed-Jones (2014) pointed out that the value used (i.e., COP path length) may not be an appropriate measurement of balance. Clark et al. (2010) made the assumption that a longer path length represented balance difficulties, when a longer path length may reflect a postural control strategy. Also, there was not a clear distinction that Clark et al. had used "raw" data from the WBB, which led others to assume that Nintendo Wii based software programs would also be valid. When the Wii based software programs were tested by Wikstrom (2012), the results showed poor concurrent validity relative to force plate COP outcomes and generally poor intrasession and intersession reliability in Wii Fit balance activity scores.

When looking specifically at literature on WBB and concussions the results are contradictory. McCarthy (2012) investigated baseline, post-concussion, and return-to-play scores on the Sideline Concussion Assessment Test (SCAT), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), and Wii Ultimate Balance Test. The SCAT and ImPACT were found to be statistically reliable, while the Wii Balance Test was not.

Another use for the WBB, as shown by Gil-Gomez, Lozano, Alcañiz and Pérez (2009), was as a tool for balance rehabilitation. Patients with an acquired brain injury (ABI) were compared results with a control group undergoing traditional physiotherapy. The results of Gil-Gomez et al. showed that the group that used the WBB had a significant improvement in static balance compared to patients that underwent traditional physiotherapy, and that both groups had significant improvements in dynamic balance. In a case study on a 17-year old TBI patient with balance deficits and unsteady gait, sessions on the WBB resulted in improvements in the Berg Balance Scale and the symmetry of weight distribution during standing (Eisenzopf, Salem & Godwin, 2010).

Though the WBB looks to be neither conclusively reliable nor unreliable when compared to a laboratory grade force-plate, the interchangeability of the devices should not be the central question. What needs to be accomplished for research to move forward is to determine when the WBB is useful, and when it is not (Stoffregen & Brady, 2014). Based on the successful results of WBB's use in rehabilitation in ABI, and the ecological relevance of the WBB for athletes, it seems further research is needed.

2.5 Attention Network Test (ANT)

Developments by Fan and Posner have allowed for a greater understanding of attention in recent years. Their findings enabled attention to be treated as an organ system with its own anatomy, circuitry and set of functions and, therefore, expanded the definition of attention to include functional and anatomical terms (Fan & Posner, 2004; Posner & Fan, 2008). Attention has also been conceptualized to be comprised of three separate components (Posner & Peterson, 1990) consisting of: alerting, orienting, and executing functions. "Alerting is defined as achieving and maintaining an alert state; orienting is the selection of information from sensory input; and executive control is defined as resolving conflict among responses" (Fan et al., 2002, p. 340).

To evaluate the three attention networks, the Attention Network Test (ANT) was designed by Fan et al. (2002). The ANT is a computerized test that requires the participant to determine whether the central arrow points left or right as quickly as possible. The arrow appears above or below a fixation point and may or may not be accompanied by flankers. Efficiency of the three attentional networks is assessed by measuring how response times and error rates are influenced by alerting cues, spatial cues, and flankers (Figure 1) (Fan et al., 2002). The initial study produced by Fan et al.

(2002) used 40 adult subjects to show that the ANT exhibited reliable single subject estimates of alerting, orienting, and executive function, and that the efficiencies of the three networks were uncorrelated.

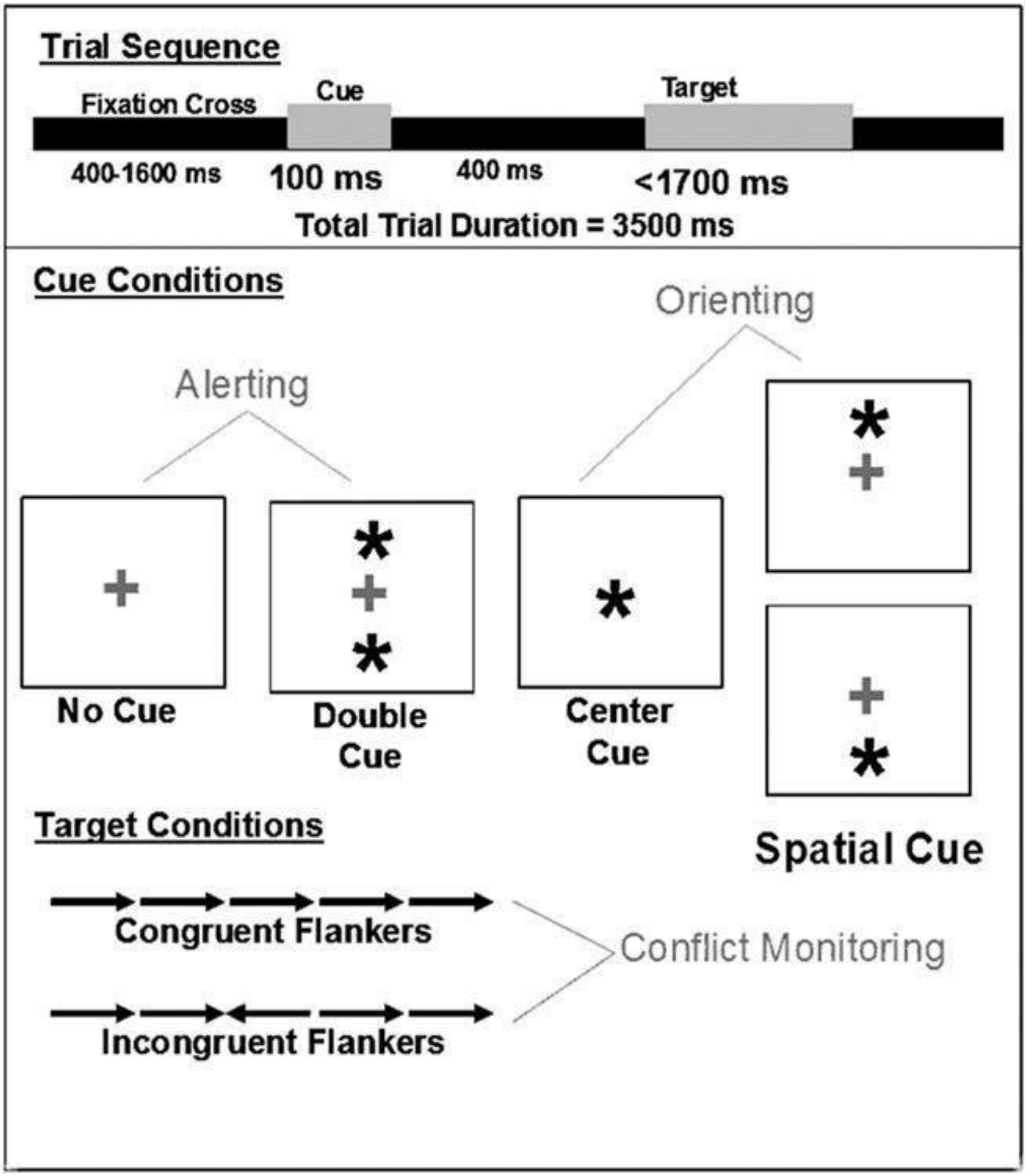


Figure 1. Trial Sequence and Timing for the Attention Network Test.
Reprinted from "Baijal, S., Jha, A. P., Kiyonaga, A., Singh, R., & Srinivasan, N. (2011). The influence of concentrative meditation training on the development of attention networks during early adolescence. Frontiers in psychology, 2. <u>*Copyright*</u> *© 2011 by Frontiers Media SA*

Studies using the ANT have been expanded and in some cases modified to test cohorts outside of healthy adults. For example, a modified ANT (mANT) was created for children using colourful fish as a replacement for the arrows to better understand the developmental stages of attention (Rueda et al., 2004). Another modification was done by Power, Faught, Przysucha, McPherson, and Montelpare (2012) who replaced the arrows with hockey players to investigate if sport-specific images affected attention. Other groups that have been studied using the ANT include individuals with psychiatric disorders like schizophrenia, attention deficit hyperactivity disorder, and borderline personality disorder. Another group that could potentially use the ANT are those that suffer a traumatic brain injury. A concussion and mTBI (mild traumatic brain injury) specific study was done at Brown and the Providence VA Medical Center by Rogg et al. (2014). They created a modified ANT that includes a distracting sounds task (e.g., beeps, buzz- es) paired with visual stimuli as a more realistic attention test for individuals (e.g., athletes, military personnel) that are under highly stimulating conditions. Using athletes diagnosed with sports-related mTBI where mANT was performed within 72 hours of injury showed that the reaction time advantage for sound compared to no-sound conditions was significantly smaller for the mTBI group compared to the control group. However, the researchers found no significant difference between the ANT and the mANT in accuracy. These results support the idea of modifying tests for ecological relevance and to test more than one specific symptom of concussion at a time.

2.6 Dynamic Balance

Though static balance stance tests like the BESS are still the most widely used balance test used in concussion assessment, it has been suggested that a longer and more accurate recovery timeline may be associated with more complex tasks (Parker, Osternig, Van Donkelaar, & Chou, 2006). One way to create a more complex balance task is to include dynamic movements. Dynamic balance requires a complex interaction of sensory input and motor output. Sensory systems monitor the location of the whole body center of mass (CoM) relative to the foot-ground center of pressure (CoP), provide orientation in space, and monitor the environment, while motor systems provide appropriate coordinated muscular activation and force generation (Parker, Osternig, Lee, Van Donkelaar, & Chou, 2005). However, there is little data available on the performance of dynamic motor tasks following concussion, even though such information could be extremely helpful and important in recommending when a person returns to pre-injury activities and athletes return-to-play (Parker et al., 2006).

Much of the previous research using dynamic balance has focused on elderly populations and fall prevention. However, in recent years there have been studies that focused specifically on concussed individuals. For example Parker et al. (2006) compared 15 concussed subjects to 15 healthy subjects over 28 days. They found that several aspects of stability (including CoM) were compromised, as well as slower movements were present in the concussed group for up to 4 weeks. Basford et al. (2003) had similar findings when comparing 10 subjects who had suffered concussion and had specific complaints of instability versus 10 control subjects. The concussed group had significantly higher CoM displacements and velocity. Chou et al. (2004) also found greater CoM motion to keep balance than controls and indications to support that concussed subjects have difficulty maintaining dynamic stability in the frontal plane and have reduced ability to arrest their sagittal momentum.

To take the interaction between sensory and motor output and add the aspect of engaging the brain, the synchronization of dynamic interaction vividly portrays participation in sport (Parker et al., 2005). One way the brain can become engaged is by adding a divided attention condition to a dynamic balance measure, which allows another layer of complexity to an already intricate task. Functionally challenging divided attention in the form of dual tasks may prove to be related to post-concussion status and provide even more pertinent information regarding optimal time for return-to-play (Parker et al., 2005).

Much of the research that has been done on dynamic balance has also included a dual task that adds the element of divided attention. In fact, Parker et al. (2005) found that along with compromised gait and slower movements, the dual task also exposed greater sway in the concussed group that also lasted the entirety of the 4 week study. The same group of researchers also performed research using 10 concussed subjects to measure dynamic balance as a single task versus dynamic balance with divided attention and found that participants were able to conservatively adjust their whole body CoM motion to maintain dynamic stability without divided attention, but demonstrated significantly greater CoM sway with divided attention (Parker et al., 2005). Howell, Osternig and Chou (2013) used adolescent subjects to perform dynamic balance tasks with the Stroop test as the dual task. They found that dual task speed was slower in the concussed group than the control group, and that CoM velocity and total CoM displacement were higher across the 2 month testing period. Also, concussed subjects were significantly less accurate on the Stroop test than the controls.

Future directions in the research area of dynamic balance are of great importance for several reasons. One reason is the potential to add weeks to the longevity of a recovery timeline for a person post-concussion (Parker et al., 2005; 2006), and therefore allowing for a more accurate assessment of symptoms, as opposed to static balance tests. Another reason is adding more complexity and movement to assessments makes tests more realistic for athletes when they return-to-play. For these reasons alone, dynamic balance assessment should not be overlooked in concussion return-to-play protocols.

2.7 Gaze stability

As previously mentioned, the instances of vestibular dysfunction as a post-concussion symptom are extremely high. Vestibular dysfunction roots from impairment of the vestibular system, which is a complex network that includes small sensory organs of the inner ear and connections to the brainstem, cerebellum, cerebral cortex, ocular system, and postural muscles (Mucha et al., 2014). The vestibular system detects the acceleration of head movements and uses the VOR to induce eye movements equal in magnitude and opposite in direction to the head movements, allowing maintenance of gaze on a stationary target while the head is moving (Mohammed et al., 2011). The system has two distinct functional units; the vestibulo-ocular system and the vestibulospinal system. While the vestibulo-ocular system maintains visual stability during head movements, the vestibulospinal system is responsible for postural control (Mucha et al., 2014).

Another aspect that can affect eye stabilization post-concussion is ocular motor impairment. Ocular motor impairment may manifest as blurred vision, diplopia, impaired eye movements, difficulty reading, dizziness, headaches, ocular pain, and poor visual-based concentration (Mucha et al., 2014). Though there is research and many tests available on the vestibulospinal facet of vestibular function, the same cannot be said of the vestibulo-ocular and ocular motor aspects, making most current vestibular assessments incomplete. This belief was mirrored by a review of the current and accepted methods available to clinicians in assessing and treating vestibular dysfunction following concussion by Gurley, Hujsak, and Kelley (2013).

Murray et al. (2014) used an eye tracking device to investigate symptoms of vestibular dysfunction and oculomotor control in athletes post-concussion versus healthy athletes. They found that the post-concussion group made significantly greater gaze deviations from center compared to the non-concussed group. Also, the post-concussion group showed significant negative correlations between gaze and balance, while the non-concussed group's relationship showed significant positive correlations between the two. These findings suggested oculomotor and vestibulo-ocular control may be important to investigate when assessing vestibular function. Gurley et al. (2013) wrote a recent review of the current and accepted methods available to clinicians in assessing and treating vestibular dysfunction following concussion. They urged dynamic gaze stability principles to be included in vestibular rehabilitation protocols for individuals post-concussion, emphasizing activities that promote adaptation of the uncompensated VOR.

Kaufman et al. (2014) also recognized the importance of examining eye movements and stabilization post-concussion. In an attempt to find a reliable test they used the dynamic visual acuity test (DVAT) and the gaze stabilization test (GST) to examine the functionality of the VOR. They found that the DVAT may be reliable, but that the GST required further evaluation. Mohammed et al. (2011) also used these two tests on patients with vestibular disorder and found that subjects' symptoms did not correlate with performance on either test suggesting refinement or enhancement of current test protocols to enhance reliability and stability for persons with vestibular disorders.

When working with concussed subjects and using Vestibular/Ocular Motor Screening (VOMS) assessment, however, Mucha et al. (2014) found that 61% of patients reported symptom provocation after at least one VOMS item. As well, all VOMS items were positively correlated to the total Post-Concussion Symptom Scale (PCSS) and the VOR component of the VOMS assessment was the most predictive of being in the concussed group. Suggesting VOMS may be a more appropriate test for vestibular and ocular motor assessment and reinforcing the importance of assessing the VOR.

Much of the research being done at this time is focused on finding a reliable test for assessing gaze stability. Although it is still one of the more recent areas of interest in concussion assessment, it does seem that researchers are starting to recognize the importance of adding tests for ocular function to the battery of tests for vestibular dysfunction. However, though it does offer the potential to be comprehensive and ecologically relevant for athletes, at this time it is not as accessible as it would need to be for untrained clinicians to use. Therefore, another point of interest is in finding a test that could be used by general clinicians and not only to the more specific, and less accessible, neuro-ophthalmology clinics.

2.8 Statistical Analysis

2.8.1 Test-Retest Reliability

Reliability refers to the consistency of a test or measurement (Weir, 2005). It is often conceptually aligned with terms such as reproducibility, repeatability, agreement, consistency, coordinance, and stability (Atkinson & Neville, 1998; Weir, 2005). However, when describing the test-retest reliability of a test or instrument, it refers to the situation in which a test is administered to a sample of subjects and then repeated at least once at another time (Vincent & Weir, 1994). This approach to testing can be used in many ways to look at different aspects of a test. One way it can be used is to analyze any changes in the participants that are being tested. An example of this would be testing a soccer player's maximum distance throw-in, and then testing them again after some time. Because this is not a skill that is typically practiced by soccer players the value should stay the same. It can also be used to focus the test, tool, or instrument that the participants are using, in this case, the participants would not undergo any changes between test periods. The current research is an example of this type, where the environments and participants were controlled to focus on the reliability of the tests specifically.

2.8.2 The Intraclass Correlation Coefficient

A metric commonly used in reliability is the intraclass correlation coefficient (ICC) (Weir, 2005). The ICC is a relative measure of reliability (Chinn & Burney, 1987) in that it is a unitless ratio of variances derived from ANOVA (Weir, 2005). Theoretically, the ICC can vary between 0 and 1.0, where an ICC demonstrating no reliability would be 0 and an ICC of 1.0 would be an expression of perfect reliability (Weir, 2005). ICC scores represent the proportion of variance in a set of scores that is attributable to the true score variance (Weir, 2005).

Though there are numerous versions and ways that ICC can be calculated (Shrout & Fleiss, 1979), this research used Winer's single score one-way model approach (Winer, 1971). A one-way ANOVA model looks at within-subject variability, unlike a two-way model that also includes between-subject variability. Also, the two differ in calculating error. Within-subject ANOVA doesn't include the "noise" due to different subjects as part of the error term because the variability due to subjects is accounted for from the repeated testing (in the test-retest design) and, therefore, not part of the error term (Weir, 2005).

2.8.3 Construct Validity

Validity is described as the ability of a measurement tool to reflect what it is designed to measure and the appropriateness of inferences made from specific measures (Atkinson & Neville, 1998; Garrett, 1937; Mahar & Rowe, 2002). The process of validation is an attempt to support the inferences of the particular population under investigation (Mahar & Rowe, 2002). The three types of validity relevant to the present study are: construct, content, and criterion validity, with the predominant focus on construct validity. Construct validity is made up of convergent and discriminant validity. Convergent validity refers to measures which demonstrate a strong correlation between measures of a construct. Discriminant validity refers to measurements that demonstrate that different constructs do not correlate as highly as measures of the same construct (Mahar & Rowe, 2002).

Chapter 3

Methodology

3.1 Research Design

This study used a within-subject repeated measures design based on a two stage test-retest data collection methodology for a non-probabilistic convenience sample. The research design was specifically intended to determine the statistical stability of the Wii Fit balance board, two visual measures (i.e., gaze deviation and centre of gaze), and three measures of attention (i.e., alerting, orienting, and executive control-decision making) based on the Attention Network Test (ANT). These measures were compared to scores on the BESS, as the established standard within the evaluation of athletes' baseline pre-concussion scores.

3.2 Participants

The study recruited twenty healthy males (n=8) and females (n=12) between the ages of 17 – 25 years. To meet the criteria of "healthy" individuals, participants did not have any disorders or injuries that would have a negative effect on their balance (free of any lower extremity injuries, ear infections, medications, neurological disorders, or visual disorders) (Appendix B and C). The research project received ethics approval and all participants signed a letter of consent before taking part in the study (Appendix A). The Wii Fit Balance Board has a weight restriction of 149 kilograms so participants were excluded if their weight exceeded that value.

3.3 Measures

There were four instruments used to attain a total of seven measures. The tests were administered two times, exactly two weeks apart, for every participant. The order of the tests was uniform for both test days (BESS, followed by ANT, followed by Wii Fit). The first tool used was the BESS foam pad (Power Systems Airex Balance Pad 81000). Each participant was prompted to adopt a series of three stances (20 seconds per stance) on both the floor and then on the foam pad as outlined by the University of North Carolina BESS protocol (Appendix D). There were three stances or conditions. The first was the double leg stance, where feet are touching (side-by-side). The second was the single leg stance where the subject stands on the non-dominant foot, with hip flexed to approximately 30° and knee flexed to approximately 45°. The non-dominant leg was defined as the leg opposite of the preferred kicking leg. The third condition was the tandem stance where the subject stands heel to toe with the non-dominant foot behind. The heel of the dominant foot should be touching the toe of the non-dominant foot. Each stance on both the floor and the foam pad was scored out of 10, with scores being deducted for every error. An error occurred if a subject opened their eyes, removed their hands from their hips, stepped, stumbled or fell, abducted or flexed the hip beyond 30°, lifted the forefoot or heel off of the testing surface, or remained out of the proper testing position for greater than 5 seconds. However, if a subject committed multiple errors simultaneously, only one error was recorded. Also, if a subject was unable to maintain a stance for a minimum of five seconds they were assigned the highest possible score, ten, for that testing condition (University of North Carolina Sports Medicine Research Laboratory, n.d.). The range of scores was 0-60, with a highest possible score being 60 and the lowest possible score being 0. Figure 2 shows the scorecard used for the BESS.

Score Card

Balance Error Scoring System (BESS)
(Guskiewicz)

Balance Error Scoring System – Types of Errors
1. Hands lifted off iliac crest 2. Opening eyes 3. Step, stumble, or fall 4. Moving hip into > 30 degrees abduction 5. Lifting forefoot or heel 6. Remaining out of test position >5 sec
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

SCORE CARD: (# errors)	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		
BESS TOTAL:		

Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

Figure 2. BESS Scorecard.
Reprinted from "University of North Carolina Sports Medicine Research Laboratory. (n.d.). Balance Error Scoring System (BESS). Retrieved from http://www.glata.org/documents/filelibrary/glata_2014_presentations/BESSProtocol_E5D9286115A3C.pdf"

The Soccer Heading Game was played using the Nintendo Wii Fit U on the Wii Fit Balance Board. When the subject played the game the Wii Fit was able to produce a game score (i.e., a numerical value) and a game rating (i.e., a single word rating). The score represented a combination of how effectively the participant was able to shift their centre of mass in an effort to move in the correct direction to head the soccer balls (out of the 80 presented each round) and avoid cleats and panda heads (distractor items). The range of scores for the game score was 0-555, whereas the ranking ranged from unbalanced (0-39), to amateur (40-199), and professional (200+). The scoring equation was +1 multiplied by X per soccer ball (i.e., where x = number of balls headed consecutively), with -1 allotted per cleat, and -3 allotted per panda head. Because the ranking was simply a less accurate measure of the overall score of the Soccer Heading Game, only the numerical score was used in statistical calculations. The distractors were manually identified as distractor hit or distractor avoided. The total number of distractors presented was 20 per trial so the number of distractors hit plus the number of distractors avoided equalled 20 for each trial. The participant played two practice trials and then was tested for on their final two trials. For a step-by-step protocol please see Appendix F.

The ASL Mobile Eye-XG eye tracking glasses consisted of two high-resolution cameras, with one recording the scene image and the other recording the corneal reflection from the participant's right eye. The eye-tracking glasses were calibrated on nine points before the subject began playing on the Wii (see Appendix G). The eye-tracking glasses were worn while the subject played four trials of the soccer heading game on the Wii Fit Balance Board. However, only data from the final two trials was recorded and scored. The measures derived while using the glasses were the number of eye deviations, as well as a centre of gaze percentage which ranged from 0-100. Both of these scores were produced by the ASL Results Plus software.

The ANT (attention network test) assessed three individual systems of attention. These systems included alerting (i.e., the ability to maintain an alert state), orienting (i.e., the ability to select incoming stimuli), and executing (i.e., the ability to resolve conflict among responses). Three scores were produced for each of the individual systems; that is, a difference score (n), a mean response time (s), and percentage of errors (%). The difference score was indicative of the difference between the prompts and the absence of prompts for the alerting, orienting, and executing conditions. The Mean Response Time for alerting, orienting, and executing was the mean reaction time for each of the tasks, while the percentage of errors was indicative of the percent of errors made during each of the tasks (see Figure 1 and Appendix E).

3.4 Variables

The measures of interest in the proposed study were the scores that each subject received on each element of each of the tests. Table 1 presents the list of measures and the corresponding metrics used in the study. The measures taken from scores on the Wii Fit Soccer Heading Game, included the overall game score, and the distractor score (i.e., the number of distractors contacted). The measures extracted from the Mobile-Eye tracking glasses were the number of eye deviations and the center of gaze score. Also included are the BESS score and the ANT score. The independent variable was the test time (i.e., test day 1 versus test day 2).

Table 1

Scoring Systems for Variables

Metrics and Range

Variable	Metric	Range
BESS	-Numerical value represents the number of errors committed per participant on all 6 stances combined	0-60
ANT	-Percentage (%) that represents the average percentage of errors committed by the participant on the three sections of the ANT (alerting/orienting/executing)	0-100%
Soccer Heading Game Score	-Numerical value +1 multiplied by X per soccer ball (x = number hit consecutively), -1 per cleat, -3 per panda head	0-555
Distractor Score	-Numerical value represents the number of cleats or panda heads the participant contacted	0-20
Gaze Deviations	-Numerical value represents the number of times the participant's gaze deviated from the area of interest (AOI)	0-∞
Center of Gaze	-Percentage (%) that represents the percentage of time the participant's gaze was fixed on the AOI out of the total time	0-100%

Notes. a) n= 20 for all measures b) ∞ = infinity, as the number of times the eye can move in 3 minutes could range from 0 to a very high number.

3.5 Statistical Analysis

Descriptive statistics, including means, standard deviations, and ranges were calculated for demographic variables such as age, weight, and height using a SAS program. SAS was also used for each of the performance measures, such as the Wii Fit Soccer Heading Game score, the BESS performance score, the number of eye-deviations, as well as the percentage of time centre of gaze was fixated.

In this reliability study, the computation of the intraclass correlation coefficient (ICC) was used to establish both stability and to demonstrate the influence of measurement error. The calculation of the Pearson Product-moment Correlation Coefficient was used to provide evidence of correlations for each test, as well as to provide construct-related evidence of validity for the use of the Soccer Heading Game to assess attention. Considering that the participants were drawn from a sample of healthy individuals ranging in age from 17-25, tests for homogeneity of variance based on Levene's Test for homogeneity of variance in test-retest analysis were used to enable the researcher to recognize the influence of underlying healthy characteristics of this cohort on the outcome measurements. The one-way intraclass correlation coefficient with test-retest was used to establish the stability coefficients and Fisher's Skewness Coefficient test were be used to demonstrate the normality of the performance scores.

The intraclass correlation was computed using the mean square error terms of the analysis variance as shown here:

$$ICC = \frac{s^2 \text{ (between trials)}}{s^2 \text{ (between trials)} + s^2 \text{ (within trials)}}$$

where: s^2 (within trials) = error from the ANOVA

r = Pearson's Product Moment Correlation Coefficient

R = refers to correlations using intraclass correlation method of Winer.

s^2 (between trials)= variance between trials/ s^2 (within trials)=variance within trials

Chapter 4

Results

4.1 Test-Retest Reliability

The sample of participants was considered representative of a cohort of healthy male and female young adults. For the purposes of this study, "healthy" was defined as being physically active (at least twice per week), and filled out online forms confirming that they were free of any lower extremity injuries, ear infections, and neurological or visual disorders. Also, participants had not suffered a concussion in the last year and were asymptomatic of any concussion-like symptoms. Average age was 21.2 (SD=2.31), average body mass was 151.9 lbs (SD=25), and average height was 172.75 cm (SD=7.20). Measures of weight and stature were taken on the initial testing day.

Test-retest reliability was calculated for each of the measures and intra-class correlation coefficients were computed using the Winer's approach. The computation of the intra-class correlation coefficient (R) for the BESS demonstrated that the BESS was a reliable test with an R score for number of errors of (R = 0.688; Mean Score $C.I._{95\%}$ = 43.2 to 50.2). The ANT demonstrated that it was a reliable test as well with as R score for percentage of errors of (R= 0.926, $C.I._{95\%}$= 1.42 to 5.62).

Measures taken while playing the Wii Fit Soccer Heading Game included two trials per test day, and R scores were calculated for each trial. For example, the overall Wii Fit score that was produced by the Soccer Heading Game demonstrated an R score for Trial 1 (day 1 and 14) of (R=0.675, Mean Score C.I.95% = 82.09 to 211.99) and improved in Trial 2 (day 1 and 14) to (R=0.898, Mean Score C.I.95%= 113.14 to 207.19). By comparison, the Distractor score extracted from the Soccer Heading Game did not demonstrate reliability, Trial 1 had an R score of (R=0.202, Mean Score C.I. 95%= 15.26 to 18.23), and Trial 2 of (R=0.561, Mean Score C.I. 95%= 15.58 to 17.42). Centre of gaze was a measure of the eye recorded by the Mobile Eye XG Eye-Tracking Glasses over the two trials of the Soccer Heading Game and demonstrated reliability over both trials with an R in Trial 1 of (R=0.883, Mean Score C.I. 95%= 93.7 to 98.1) and an R in Trial 2 of (R=0.803, Mean Score C.I. 95%= 93.07 to 98.63). Gaze deviation was also is a measure of the eye recorded by the Mobile Eye XG Eye-Tracking Glasses over two trials of the Soccer Heading Game and demonstrated reliability over both trials with an R in Trial 1 of (R=0.64, Mean Score C.I. 95%= 2.16 to 5.5) and an R in Trial 2 of (R=0.748, Mean Score C.I. 95%= 1.89 to 5.71). The R values calculated with ICC for all measures are graphed in Figure 3. Descriptive statistics including means, standard deviations, standard error, and confidence intervals are shown in Table 2.

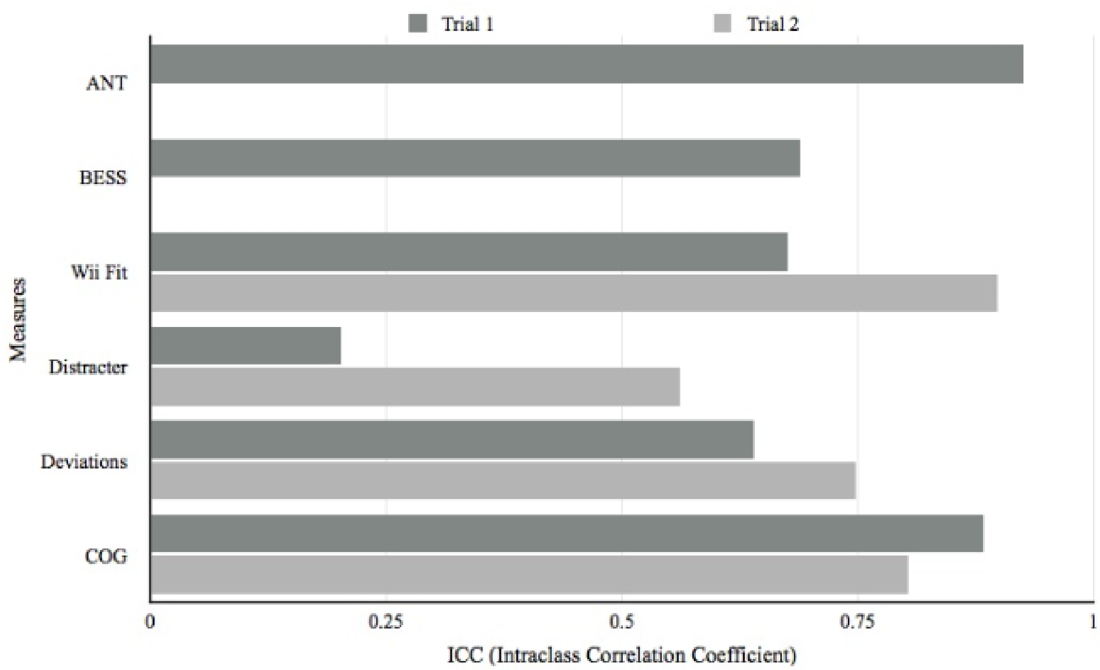


Figure 3. Test-Retest ICC Values By Measure
Note: The ANT and BESS require 1 trial, while measures taken on the Wii Fit have 2 trials.

Table 2

Descriptive Statistics

Measure	Day	x̄	SD	n	Se	95% CI	R
Gaze Deviations Trial #1	1	3.95	3.53	20	0.79	±1.55 2.40-5.5	0.64
Gaze Deviations Trial #1	14	3.15	2.25	20	0.50	±0.99 2.16 to 4.14	
Gaze Deviations Trial #2	1	4.20	3.44	20	0.77	±1.51 2.69 to 5.71	
Gaze Deviations Trial #2	14	3.10	2.77	20	0.62	±1.21 1.89 to 4.31	0.748
Center of Gaze Trial #1	1	95.85	4.30	20	0.96	±1.88 93.97 to 97.73	
Center of Gaze Trial #1	14	95.9	5.01	20	1.12	±2.2 93.7 to 98.1	0.883
Center of Gaze Trial #2	1	95.85	3.48	20	0.78	±1.53 94.32 to 97.38	
Center of Gaze Trial #2	14	95.85	6.34	20	1.42	±2.78 93.07 to 98.63	0.803
Overall Wii Fit Trial #1	1	119.65	85.71	20	19.17	±37.56 82.09 to 157.21	
Overall Wii Fit Trial #1	14	177.2	79.38	20	17.75	±34.79 142.41 to 211.99	0.675

Overall Wii Fit Trial #2	1	146	74.97	20	16.76	±32.86 113.14 to 178.86	0.898
Overall Wii Fit Trial #2	14	171.95	80.41	20	17.98	±35.24 136.71 to 207.19	
Distractor Trial #1	1	16.10	1.92	20	0.43	±0.84 15.26 to 16.94	0.202
Distractor Trial #1	14	17.40	1.90	20	0.43	±0.83 16.57 to 18.23	
Distractor Trial #2	1	16.45	1.67	20	0.37	±0.73 15.72 to 17.18	0.561
Distractor Trial #2	14	16.5	2.09	20	0.47	±0.92 15.58 to 17.42	
BESS	1	46.8	7.68	20	1.72	±3.37 43.43 to 50.17	0.688
BESS	14	46.65	7.88	20	1.76	3.45 43.2 to 50.1	
ANT	1	3.85	4.03	20	0.90	±1.77 2.08 to 5.62	0.926
ANT	14	2.76	3.06	20	0.69	±1.34 1.42 to 4.1	

Notes. R Values represent intraclass correlation coefficients for each trial in a test-retest design, whereby the retest was conducted 14 days following the initial test.

Table 2

4.2 Correlations

There was a significant positive correlation between the BESS and the overall Wii Fit score (r = 0.37, n=20, p = 0.02), as well as between the BESS and COG (r= 0.39, n=20, p= 0.01), while the relationship between the BESS and Deviations demonstrated a significantly negative correlation (r= -0.40, n=20, p= 0.01). The BESS and ANT also demonstrated a nonsignificant negative correlation (r= -0.12, n=20, p= 0.47), as did the BESS and Distractor scores (r=-0.21, n=20, p= 0.19). The Distractor score also showed a negative correlation with the ANT (r= -0.02, n=20, p= 0.89), and COG (r= -0.26, n=20, p= 0.10). However, the Distractor score demonstrated a significant positive relationship with Deviations (r= 0.31, n=20, p= 0.05). Deviation scores also demonstrated a significant negative relationship with COG (r= -0.70, n=20, p= <.0001). COG demonstrated a positive, yet non-significant, relationship with the ANT (r= 0.01, n=20, p= 0.94), and with the Overall Wii Fit score (r= 0.20, n=20, p= 0.21). Overall Wii Fit demonstrated a significant negative relationship with Distractor score (r = -0.74, n=20, p <.0001). Overall Wii Fit also demonstrated a marginally significant negative relationship with Deviations (r= -0.29, n=20, p= 0.07) and a positive non-significant relationship with the ANT (r= 0.10, n=20, p= 0.56). The ANT and Deviation scores displayed a negative correlation (r= -0.02, n=20, p= 0.90).

Table 3

Pearson's Correlations Among Variables

	1	2	3	4	5	6
1.Overall Wii Fit	1.00					
2.Distractor	r= -0.74 ***p=<.0001	1.00				
3. BESS	r= 0.37 *p= 0.02	r= -0.21 p= 0.19	1.00			
4. ANT	r=0.10 p= 0.56	r= -0.02 p= 0.89	r=-0.12 p= 0.47	1.00		
5. Gaze Deviations	r=-0.29 p= 0.07	r=0.31 *p= 0.05	r=-0.40 *p= 0.01	r=-0.02 p= 0.90	1.00	
6. Center of Gaze	r= 0.20 p= 0.21	r= -0.26 p= 0.10	r= 0.39 *p= 0.01	r= 0.013 p= 0.94	r= -0.70 ***p=<.0001	1.00

Notes. a)*p< .05. **p< .01. ***p< .001 b) n=20 c) r=Pearson's Product Moment Correlation Coefficient d) Distractor and Deviation correlation 0.0499 prior to rounding

Table 3. Pearson's Correlations

Chapter 5

Discussion

5.1 Summary of Findings

The primary purpose of this study was to measure the reliability of the BESS, ANT, Wii Fit Soccer Heading Game, and components of the ASL Mobile-Eye Tracking Glasses. The results provide evidence that the ANT, BESS, overall Wii Fit Soccer Heading Game score, Eye Deviations, and Center of Gaze were reliable (Figure 3) using the test- retest method, while the Distractor score of the Soccer Heading Game showed lower reliability (Figure 3).

The results indicate that these tests are stable when measuring healthy young adults. Likewise, the findings are in agreement with previous research on participants from similar demographic cohorts for the BESS when the issue of inter-rater reliability was nullified, as it was in this study (Finnoff et al., 2009; McLeod et al., 2004; Riemann, Guskiewicz, & Shields, 1999). Similarly, the ANT also showed reliability results that were comparable to previous literature (Fan & Posner 2002; Ishigami & Klein 2010). These tests are often used to test higher-risk groups like seniors, children, individuals post-injury, so it was not surprising that the reliability numbers for both of these tests with young healthy adults were strong. The level of stability supports the use of these tests in cohorts that are deemed to be of a higher risk for injury. The visual measures that were assessed using the ASL Mobile-Eye Tracking Glasses also showed reliability when used while playing the Soccer Heading Game on the Wii Fit. This was to be expected as participants were screened for any disorders of the eye that would affect the reliability, negatively.

Reliability of the Wii Fit Balance Board has been debated in recent literature (Clark et al., 2010; Reed-Jones, 2014; Wikstrom, 2012). However, the device demonstrated acceptable estimates of test-retest reliability when applied in the current research study. Despite the ongoing debate of how the Wii Fit Balance Board compares to a laboratory grade force plate, the device was shown to be an effective tool in providing consistent estimates for pre- and post-test balance. In addition, the results in this study provide some evidence that the Soccer Heading Game is a reliable balance measure and when combined with visual tracking hardware provides a useful approach by which to assess gaze and gaze deviations -- two measures of visual reflex that can be used as baseline assessments in concussion screening.

An important measurement in this research study was to establish construct validity, and the two sub-types: convergent and discriminant validity, by assessing whether the Soccer Heading Game was valid as an attention-driven dynamic balance task. Construct validity, which can be described as the extent to which measurements relate to a specific construct is comprised of convergent validity -- the extent to which two or more constructs converge to support a relationship; and discriminant validity -- the extent to which unrelated measures remain unrelated and do not demonstrate correlations

(Messick, 1993). In the present study two important constructs were attention and balance. The Soccer Heading Game distractor scores were compared to the balance scores on the BESS and to the separate attention network scores: alerting, orienting, and executing from the ANT. If construct validity for these two tests was demonstrated then the Wii Fit distractor score could be used in the place of the ANT for a measure of attention, making the Soccer Heading Game, in conjunction with the WBB, a measure of attention-driven dynamic balance. The relationship between the ANT and the Soccer Heading Game distractor score did not exhibit the convergent validity needed for the distractor score to demonstrate construct validity. There was a negligible relationship ($r = -0.02300$, $p = 0.8880$) between the two measures, suggesting the distractor score is not an accurate measure of attention. In fact, the ANT did not show a strong correlation with any of the measures involved in the study (Table 3). This finding, along with the relationship between the Soccer Heading Game and the BESS, suggests that although attention is required to play the Wii Fit Soccer Heading Game, it is difficult to isolate a measure within the game without balance having some effect on the score.

Conversely, the relationship between the balance scores as determined by the BESS and the distractor scores from the Soccer Heading Game exhibited the expected discriminant validity. There was a weak negative nonsignificant correlation ($r = -0.21254$, $p = 0.1879$), meaning that as individual BESS scores decreased the number of distractors that were contacted seemed to increase and similarly, as individual BESS scores increased the number of distractors contacted seemed to decrease. This seems to suggest, however, that though a weak relationship, the distractor is still partially linked to balance. Based on the understanding that balance, both dynamic and static, is determined partially by vestibulo-spinal tract it is plausible that a relationship exists, as both the BESS and the Soccer Heading Game are measures of vestibular control. This suggests that the distractor cannot be extracted from the Soccer Heading Game score as a measure that solely targets attention.

Another interest of this research was to analyze the relationship between body and eye stabilization. It was hypothesized that the two measures of stabilization would correlate, suggesting that increases and decreases in body stabilization (as exhibited by the Soccer Heading Game score) would relate to increases and decreases in eye stabilization scores (as exhibited by COG and eye deviations inversely). To reach this conclusion, first, it had to be shown that the two eye measures were significantly and negatively correlated. As shown in the results in Table 3 with a correlation of ($r = -0.70011$, $p = <.0001$) this was shown to be true. This is important in practice because disparity between the two eye measures may suggest optic motor or vestibulo-ocular dysfunction, which could negatively affect an individual's recovery and subsequent return-to-play in their sport.

Secondly, it was important to consider the correlations between the eye measures and the Soccer Heading Game score. COG showed a weak positive relationship to the Soccer Heading Game score while eye deviations showed a weak negative relationship. There is a possibility that the correlations may have been stronger with a larger sample size, however, even with weak correlations the directions of both measures seem to suggest that healthy individuals show a correlation between eye and body stabilization when all measures are performed on the Wii Fit device.

One correlation in the category of body and eye stabilization that was not hypothesized but that exhibited a positive significant relationship was between the BESS and selected visual measures: COG and gaze deviations ($r=0.37$; $p<0.05$). In fact, this correlation was even stronger than between the Wii and eye measures (Table 3). This relationship was not unexpected because the BESS is performed with the eyes closed. However, the significant positive correlation supports the notion that body and eye stabilization will occur simultaneously, as the BESS is another measure of body stabilization. This finding suggests that because healthy individuals show strong correlations between body and eye stabilization, a lack of correlation on these measures may be an indicator of vestibular dysfunction. Individuals that do not demonstrate a relationship between body and eye stabilization may be cautioned against returning-to-play until the two areas of stabilization are working in conjunction. For future research it would be helpful to study whether this correlation is lacking in concussed individuals, and how long the disparity in this relationship occurs post-concussion.

5.2 Limitations

Limitations were identified in this study that should be addressed in future research. The first limitation is related to the selection of measurements. The Wii Fit Soccer Heading Game was the only test that measured dynamic balance, and for validity it would have been useful to compare measures on the Wii Fit Soccer Heading Game to another measure of dynamic balance, more specifically a previously-tested divided attention measure of dynamic balance. A second limitation was that the researcher could not prevent the participants from playing the Soccer Heading Game during the time between the two test days. A third limitation may have been in the homogeneity of the sample. Although, subjects were considered to be healthy and had previously participated in organized sports, the levels of athletic participation ranged from casual recreation to varsity. This, in combination with the different sports in which the subjects participated, may suggest different athletic abilities, and may have had an effect on scores in tests like the Wii Fit. It is recommended that in future research, the sample consist of participants from higher-risk groups, specifically concussed individuals to determine the extent to which estimates of reliability may be influenced by different conditions.

5.3 Conclusions

The overall Wii Fit score demonstrated reliability consistent with the BESS. Because the Soccer Heading Game has many more elements of ecological relevance for athletes, it is a more appropriate test to use when assessing an athlete's balance. One of the added elements of ecological relevance is the inclusion of a visual aspect in the test. By assessing the eye movements, and demonstrating stability, the opportunity exists for further exploration and research on higher-risk populations like those with head injuries. This study suggests a link between eye and body stabilization in healthy individuals. Further investigation is required to understand the effect a head injury has on the relationship.

5.4 Future Research

One of the most important aspects of this research was that it considered the concept of ecological relevance within the establishment of baseline concussion assessment and return to play decision making. The tests were chosen for their potential to be more ecologically relevant and thorough tests for athletic populations and to more comprehensively examine deficits caused by head injuries in those athletes. Because the more ecologically relevant tests showed consistent reliability, it is suggested that they be used in assessment and management of head injuries in sport. Also, because the measures of gaze showed consistent reliability, and an inverse relationship to each other in healthy populations, it is suggested that the effect of head injuries on these measures be examined further.

Appendix A

Letter of Consent

Some basic guiding principles for the partnership between the researchers and the participants:

I have read the information sheet for this study and have been given permission to print any information I wish. I have also been provided a contact number of the Principal Investigator and an invitation to ask questions about the study or my participation in the study.

I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected and I give consent for any data already given to be retained and used.

I understand that I will not benefit financially if this study leads to the development of education and training or future research/education/technological developmental outcomes.

I know how to contact the study team if necessary. I understand that I can contact the UPEI Research Ethics Board at (902) 620-5104, or by email at reb@upei.ca if I have any concerns about the ethical conduct of this study.

I understand that by submitting the letter of informed consent with this study I am agreeing to participate in this study.

I understand that a written summary of the findings will be available to participants through reports produced by the study team and disseminated via professional and academic journals and conferences.

AUTHORIZATION

If you would like to participate in this research, please print this page and sign your name and date on the lines below. Please bring this form with you when you visit the UPEI Evaluation Clinic in the lower level of the Steel Building. This signed form is necessary for you to participate.

I have read the information provided for the research conducted at UPEI related to establishing baselines for concussion screening as described in the associated information page. My questions have been answered to my satisfaction and I agree to participate in this study. I voluntarily choose to participate in this study, but understand that my consent does not take away my legal rights in the case of negligence or other legal fault of anyone who is involved in this study. I have been

given a signed copy of this consent form.

❐ <-- By checking this box I am allowing any test results to be shared with UPEI

Healthcare professionals (ex. Physiotherapists or team doctors) or coaches

Name of Participant: ______________________________________

Signature: ______________________________________

DATE: ____________________________

After printing this page, please click on the link entitled to Participation Information to begin surveys, below.

Appendix B

Participant Information

Participant Information
Today is:

First Name	
***Surname**	
Telephone	
Email	
	Select Sex
	Male Female
	Please enter birth-DAY
	Please enter birth-MONTH (e.g. August= 08)
	Please enter birth-YEAR
	Indicate Highest Level of Education
	Current Health Conditions
	Are you taking any medications? If so, please provide name
	If you have experienced a concussion, please indicate the sport and date in which you were participating when concussed.

	Check the box beside the condition if you currently experience any of the following conditions: ❒ **a lower extremity injury** ❑ **an ear infection** ❑ **a neurological disorder** ❑ **a visual disorder**
	*** denotes required field**

Appendix C

Concussion History

First Name*______________________________.

Surname*_________________________________.

1. If you have experienced a concussion at some point in your life, please indicate date (and time if known) of most recent concussion
Date:
Time:

2. How many concussions have you experienced during the past 2 years?

Games/Practices:
Other Activities:

3. Indicate the number of concussion episodes that were treated by medical/healthcare professionals:

4. Even if you have NEVER experienced a concussion, please rate yourself on each of the following concussion-like symptoms you have experienced in the past two weeks:

	None	Mild	Moderate	Severe
Headache				
Pressure in Head				
Neck Pain				
Nausea or Vomiting				
Dizziness				
Blurred Vision				
Balance Problems				
Sensitivity to Light				
Sensitivity to Noise				

Feeling Slowed Down				
Feeling Like "in a fog"				
Do Not Feel "Right"				
Difficulty Concentrating				
Difficulty Remembering				
Fatigue or Low Energy				
Confusion				
Drowsiness				
Trouble Falling Asleep or Sleeping More				
More Emotional				
Irritability				
Sadness				
Nervous or Anxious				

Add Comments Here:

Reset Form **Submit Form**

***denotes required field**

Appendix D

BESS Protocol and Script

Balance Error Scoring System (BESS)

1. Participants are asked to remove their shoes and to identify their dominant foot/leg.

2. The participant is first asked to stand in the Double Leg Stance (standing on flat surface with feet side by side (touching), hands on the hips and eyes closed) for 20 seconds as the examiner looks for errors (errors include moving the hands off the hips, opening the eyes, stepping out of the stance, stumble or fall, abduction or flexion of the hip beyond 30˚, lifting the forefoot or heel off of the testing surface, remaining out of the proper testing position for greater than 5 seconds). Once the 20 seconds is complete the examiner records the number of errors in the time period.

3. The examiner instructs the participant to take the Single Leg Stance (standing on flat surface on the non-dominant foot, hip flexed to 30º and knee flexed to ~45º, hands on hips and eyes closed) for 20 seconds as the examiner notes the number of errors.

4. The examiner directs the participant to take the Tandem Stance (standing heel to toe on a firm surface with the non-dominant foot in the back, heel touching toe of other foot, hands on hips and eyes closed) for 20 seconds while noting the number of errors.

5. The Participant is then instructed to repeat the Double Leg Stance, Single Leg Stance, and Tandem Stance on the foam surface, provided with the test, and the examiner again notes the number of errors per stance.

6. The scores (number of errors) are recorded for a total score out of 60.

"*For this experiment you'll have to take off your shoes and identify your non-dominant foot. For this test we will be doing a series of three different positions. You will hold each position for 20 seconds. Then each position will be repeated on a foam pad. So to start, you have to take the Double Leg Stance by standing in the middle of the square on both of your feet about shoulder width apart, and closing your eyes. When you're ready, I'm going to time you for 20 seconds. Go."*

“Now, you’ll take the Single Leg Stance by standing on your non-dominant foot with your dominant knee bent at a 45-degree angle, and closing your eyes. When you’re ready I’ll time you for 20 seconds. Go.”
“Now, you will take the Tandem Pose by standing heel to toe with your non-dominant foot in back and your heel touching your toe, and closing your eyes. When you’re ready, I will time you for 20 seconds. Go.”

“Now, you have to perform those same positions, in the same order, on the foam block. First the Double Leg Stance, then the Single Leg Stance, and finally the Tandem Pose. So again, I will time you for 20 seconds on each of these positions. And just like before, you can take a pause in between positions to get into position. Let me know when you are ready and I will begin timing. Go.”

Appendix E

ANT Protocol

The ANT protocol consists of four sections. The first is a practice trial (2 minutes) while the remaining three are test sessions (5 minutes each). Participants have the option of taking a short break between test sessions. The entire experiment takes approximately 20 minutes.

1. Participant is asked to sit at the computer.
2. They are told to identify the direction of the central arrow, which sits in between other arrows as quickly as possible after it flashed on the screen. The direction of the central arrow may be congruent, incongruent, or neutral with the direction of the surrounding arrows (flankers).
3. They are told that there will be a practice trial and that those scores are not recorded.
4. After the practice trial is completed they will begin the test and follow the same instructions as the practice trial.
5. The test administrator remains in the room in case any questions arise while test is being administered.
6. When test is done the participant's score is saved under their ID.

Appendix F

Wii Fit Soccer Heading Game Protocol and Scorecard

1. Make sure Wii is plugged into extension cord and that the cord is plugged into the wall inside room 137.

2. Turn on Wii (the power button will turn from red to blue)

3. Turn on Wii Controller (power button on front right lower corner)

4. Make sure HDMI cord is connected to the wall and the back of the Wii.

5. Turn on overhead projector (press power button) and make sure the "Input" option is set to HDMI.

6. Place Wii Balance Board on the floor directly under the overhead projector.

7. Select Wii Fit option on the touch screen controller (top left corner).

8. Enter Passcode ("4646").

9. Select Heading Soccer Game

10. Turn on Wii Fit Balance Board (power button can be touched with toe as instructed on screen)

Instructions to the participant:

1. *Take off shoes and stand on board (when prompted on screen).*
2. *"Focus on the net in the middle of the screen, there are going to be soccer balls kicked at you and you must, keeping both feet planted, shift your weight to the left and to the right to move the player. Also, there are going to be cleats and panda heads that you try to avoid, as getting hit will take points of your score. Bending your knees and remaining in an athletic stance can help with control."*
3. *"You are going to have 2 practice rounds and then 3 scored rounds, we will use the top two scores of your scored attempts".*
4. *"Are you ready?"*

11. When the subject is ready click start.

12. The subject will play two practice rounds with no scores recorded.

13. At the end of each game it will ask “Quit” or “Retry”, click “Retry”.

14. Have scoring system open for final 2 rounds.

15. For the scored rounds it will be noted every time a distractor (panda head or cleat) is kicked, and whether or not the subject avoids the object.

16. When the game is over (for the 2 scored rounds) the scores per trial produced by the Wii will be recorded, as well the number of distractors (panda heads and cleats) that were contacted out of 20 per trial.

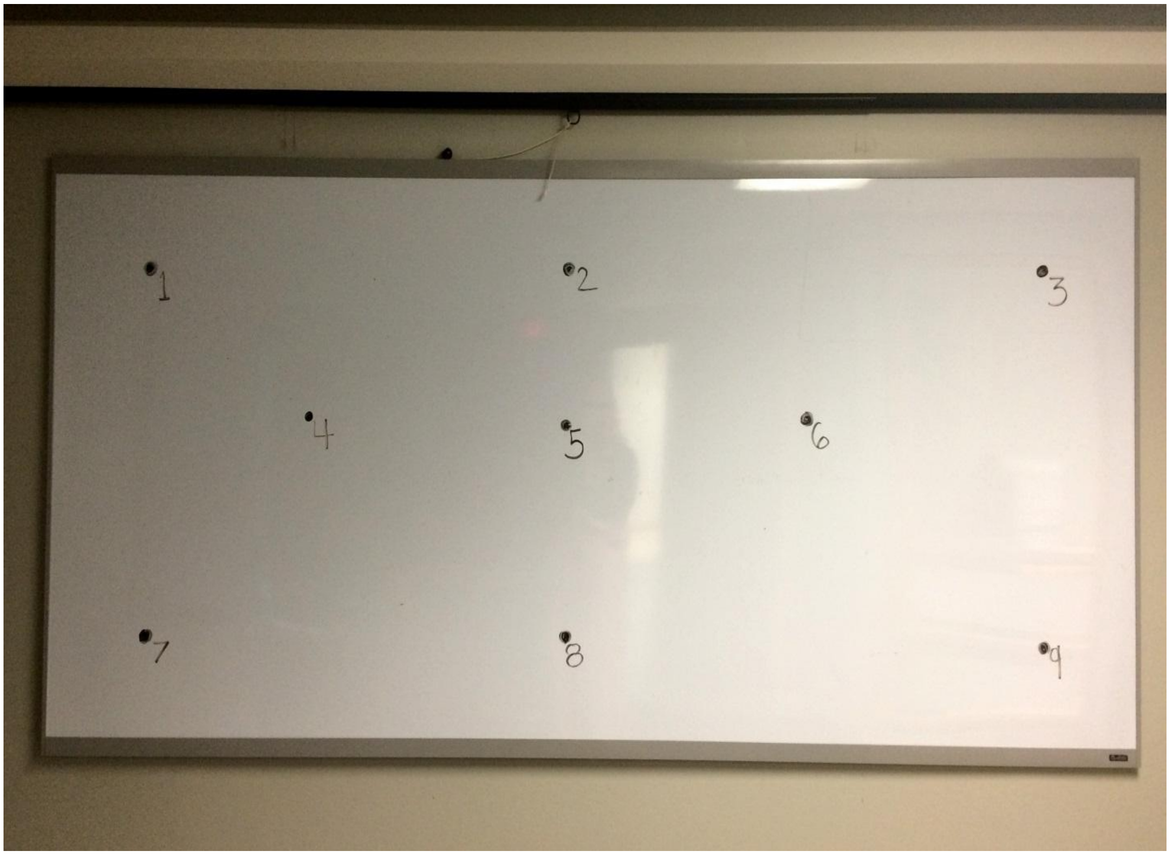
Soccer Heading Game Scorecard

Participant ID:

	Overall Wii Fit Score	**Distractors Contacted /20**	**Distractors Avoided /20**
Trial 1			
Trial 2			

Appendix G

ASL Mobile Eye Calibration Sequence/Protocol



Protocol:

1. Glasses are placed on participants head and strap is tightened behind the head.

2. Participants are asked if comfortable. Make any necessary adjustments until the glasses feel snug and comfortable on head.

3. Participants are asked not to touch face, head, or glasses until it is time to remove the glasses at the end of testing trials.

4. Participant stands on the Wii Fit Balance Board and is told to keep head completely still.

5. Participants are instructed to look at the dot beside the number when they are prompted, and to keep looking at point until they are instructed to look at a different numbered dot.

6. On the ASL Mobile Eye XG Software/Laptop the scene image is visible and when the participant is looking at the calibration point the person administering the test clicks on the corresponding dot.

7. The glasses are calibrated on all 9 points for each specific participants eye and saved under the participant's ID in the software.

8. Once the glasses are calibrated the overhead is prepared for the Soccer Heading Game to be played. Before the first trial starts the test administrator presses record on the glasses.

9. At the end of the trials press the record button again (turning off the recording), and remove the glasses from the participant's head.

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